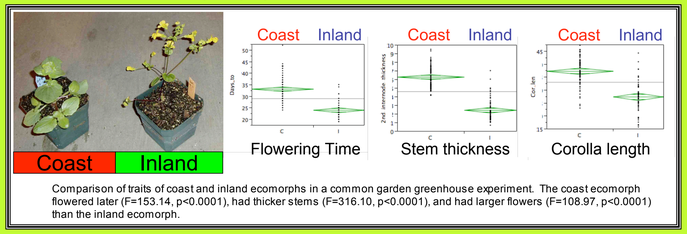
Adaptive divergence and ecological reproductive isolation between two ecomorphs at a large geographic scale

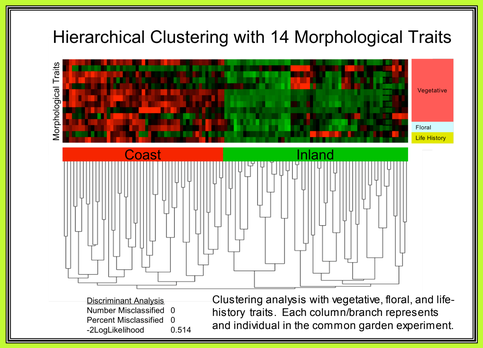
David B. Lowry and John H. Willis
Duke University, Program in Genetics and Genomics
Duke University, Biology Department, Durham, NC 27708

Morphological Divergence

•We conducted a common garden greenhouse experiment to determine if there is a genetic basis to the morphological and life-history divergence of Coast and Inland *Mimulus guttatus*.
•Seven pairs of coast and inland populations
•Twelve individuals per population

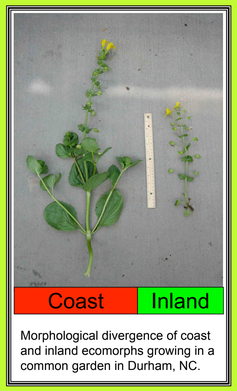


Comparison of traits of coast and inland ecomorphs in a common garden greenhouse experiment. The coast ecomorph flowered later (F=153.14, p<0.0001), had thicker stems (F=316.10, p<0.0001), and had larger flowers (F=108.97, p<0.0001) than the inland ecomorph.



Clustering analysis with vegetative, floral, and life-history traits. Each column/branch represents and individual in the common garden experiment.

There is a clear genetic basis to the divergence of coast and inland ecomorphs



Morphological divergence of coast and inland ecomorphs growing in a common garden in Durham, NC.

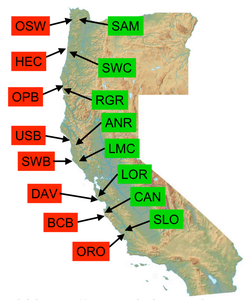
Coast and Inland Ecomorphs of *Mimulus guttatus*

Inland Ecomorph

•Thin stems and small leaves
•Flowers in spring
•Almost always annual
•Life-history likely determined by lack of soil moisture in the summer, due to high temperatures and dry conditions.
•Found in seeps, annual grasslands, and along river banks

Coast Ecomorph

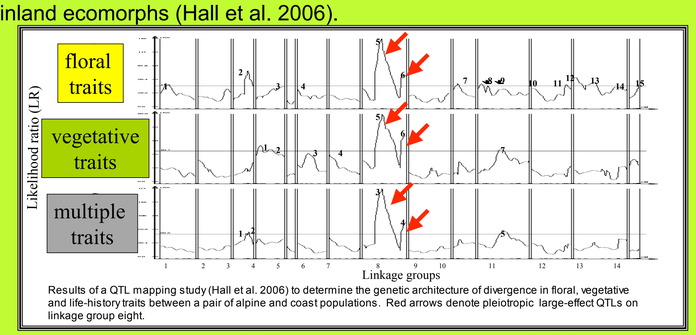
•Large stems and leaves
•Flowers mid-summer
•Perennial life-history with some clonal reproduction
•Life-history likely determined by abundant soil moisture in the summer, as a result of low temperatures and persistent fog.



•We collected 15 pairs of coast (Red) and inland (Green) populations at different latitudes in Oregon and California.
•Distance between populations in a pair ranged from 9 to 61 km.

Ongoing Research: Landscape Genomics

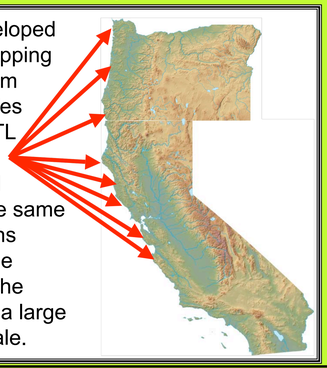
Inland and coastal *Mimulus guttatus* are morphologically and genetically structured ecomorphs. In addition, a previous QTL mapping study demonstrated that two pleiotropic loci each contribute 20-30% to the divergence of vegetative, floral, and life-history traits between coast and inland ecomorphs (Hall et al. 2006).



Results of a QTL mapping study (Hall et al. 2006) to determine the genetic architecture of divergence in floral, vegetative and life-history traits between a pair of alpine and coast populations. Red arrows denote pleiotropic large-effect QTLs on linkage group eight.

However, this study was limited to one pair of coast and alpine populations. Therefore, we are now testing whether the same genomic regions contribute to morphological and life-history divergence over the range of the coastal ecomorph.

•We have developed multiple F2 mapping populations from different latitudes for targeted QTL mapping.
•This study will determine if the same genomic regions contribute to the divergence of the ecomorphs on a large geographic scale.

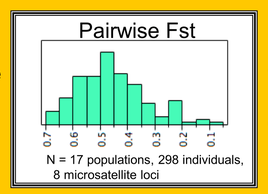


•Field experiments with near isogenic lines (NILs) will determine if these large effect QTLs are adaptive.

•Fine mapping will determine if there are multiple genes underlying these large effect QTLs.

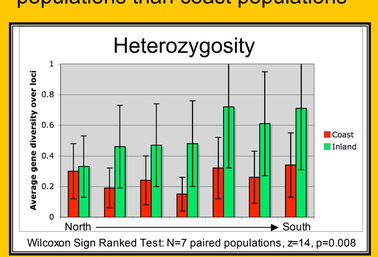
Population Structure

•We conducted a population genetic survey to determine if there is neutral genetic structure between the ecomorphs
•Our data set included 8 coast and 10 inland populations
•16-20 individuals in each population were genotyped at eight microsatellite loci

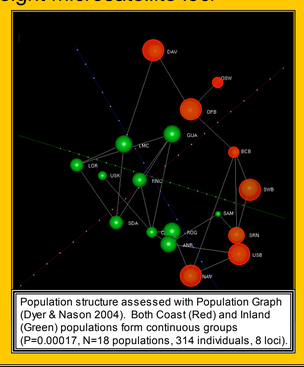


•Fst was high in all pair-wise comparisons.

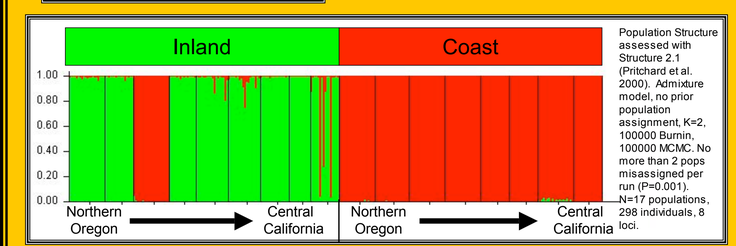
•Heterozygosity was greater in inland populations than coast populations



•Both microsatellite and sequence data detected population structure between coast and inland ecomorphs.



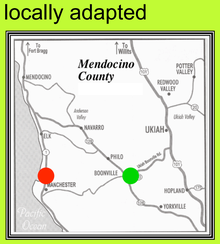
Population structure assessed with Population Graph (Dyer & Nason 2004). Both Coast (Red) and Inland (Green) populations form continuous groups (P=0.00017, N=18 populations, 314 individuals, 8 loci).

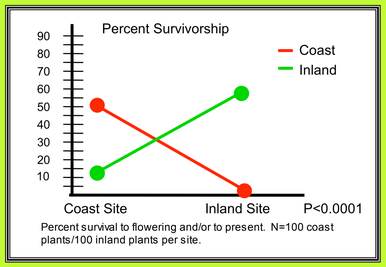


Population Structure assessed with Structure 2.1 (Pritchard et al. 2000). Admixture model, no prior population assignment, K=2, 100000 Burnin, 100000 MCMC. No more than 2 pops misassigned per run (P=0.001). N=17 populations, 298 individuals, 8 loci.

Reciprocal Transplant Experiment

•We set up a reciprocal transplant experiment set up in Northern California to determine if the ecomorphs are locally adapted





Percent survival to flowering and/or to present. N=100 coast plants/100 inland plants per site.

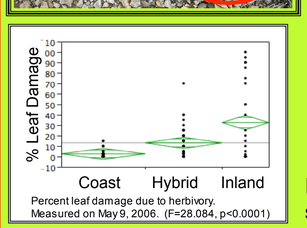
•Clear evidence of local adaptation
•Possible temporal reproductive isolation, due to flowering time differences between ecomorphs (Data collection in progress)

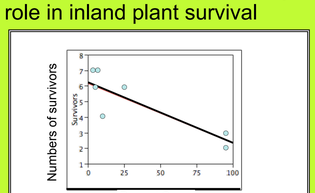
Each Site
•100 Inland plants
•100 Coast plants
•100 F1 Hybrids

Selection at the Coastal Site

•Inland plants suffered high levels of herbivory

•Competition with the perennial plant community played a major role in inland plant survival

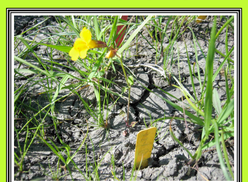




Inland plant survivorship as a function of percent cover of vegetation in a block (N=7 blocks, 10 inland plants per block, R^2=0.7503, p=0.0117).

Is competition a factor in the large size of the coastal ecomorph?

Selection at the Inland Site



Inland plants flowered before drought

Only one coast plant survived to flower

Conclusions

•Coast and Inland populations of *Mimulus guttatus* comprise morphologically and genetically structured ecomorphs, which have a parallel distributions over a large geographic range.
•Both abiotic (drought) and biotic (herbivory/competition) factors contribute significantly to the local adaptation of these ecomorphs and thus, may play a role in ecological reproductive isolation (Nosil et al. 2005).
•The genetic/genomic resources of *Mimulus guttatus* are rapidly expanding and will facilitate future research.
•This system provides the opportunity to study the genetic basis of ecological reproductive isolation as well as the role of abiotic and biotic factors in morphological and life-history evolution.

Acknowledgements

Field Work and Collections: Cotton Rockwood and Kevin Wright
Permission for field experiments: Scott Fraser, Pete Bradford, and the UC Reserve System
Advice: Joe Hereford, Matt Streisfeld, Cynthia Riginos, Brian Counterman, Mohamed Noor, Jenny Tung, David Garfield, Kurt Merg, Meleah Hickman, and the Willis Lab
Funding: NSF FIBR, Duke University Travel Grant, NIH pre-doctoral training fellowship

References

•Dyer, R.J. and J.D. Nason. 2004. Population Graphs: The Graph-Theoretic Shape of Genetic Structure. Molecular Ecology. 13(7): 1713-1728.
•Hall, M.C., C.J. Basten and J.H. Willis. 2006. Pleiotropic quantitative trait loci contribute to population divergence in traits associated with life-history variation in Mimulus guttatus. Genetics 172:1829-1844.
•Nosil, P., T. Vines and D.J. Funk. 2005. Perspective : Reproductive isolation caused by natural selection against immigrants from divergent habitats. Evolution 59 : 705-719.
•Pritchard, J.K., M. Stephens and P.J. Donnelly. 2000. Inference of population structure using multilocus genotype data. Genetics 155: 945-959.